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**Nagendra et al.**

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- (54) **METHODS AND STRUCTURE FOR SERIAL ATTACHED SCSI EXPANDERS THAT SELF-CONFIGURE BY SETTING ROUTING ATTRIBUTES OF THEIR PORTS BASED ON SMP REQUESTS**
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- (\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 171 days.

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(57) **ABSTRACT**

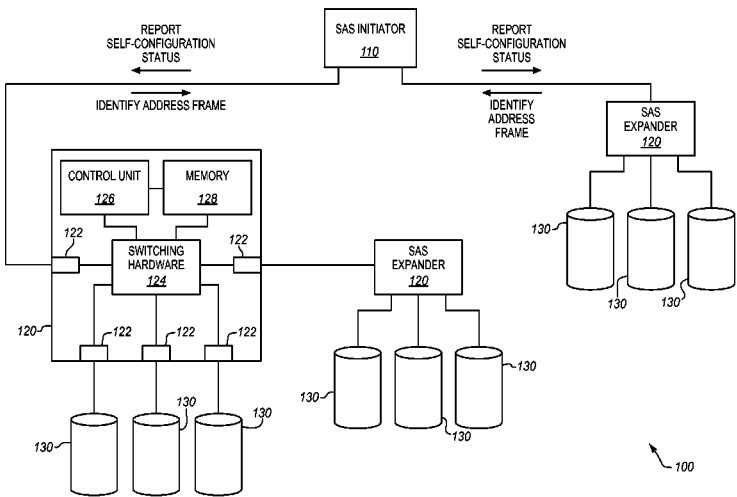
Methods and structure are provided for Serial Attached SCSI (SAS) expanders that program their own routing attributes. The structure includes a SAS expander comprising multiple physical links with associated transceivers (PHYs), wherein the PHYs are configured into ports at the expander, and a memory that defines routing attributes for each of the ports. The SAS expander also comprises a control unit that is operable to detect a discovery Serial Management Protocol (SMP) request received at a port of the expander, and that is further operable to set the routing attribute for the port to subtractive routing responsive to detecting the SMP request.

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**20 Claims, 4 Drawing Sheets**



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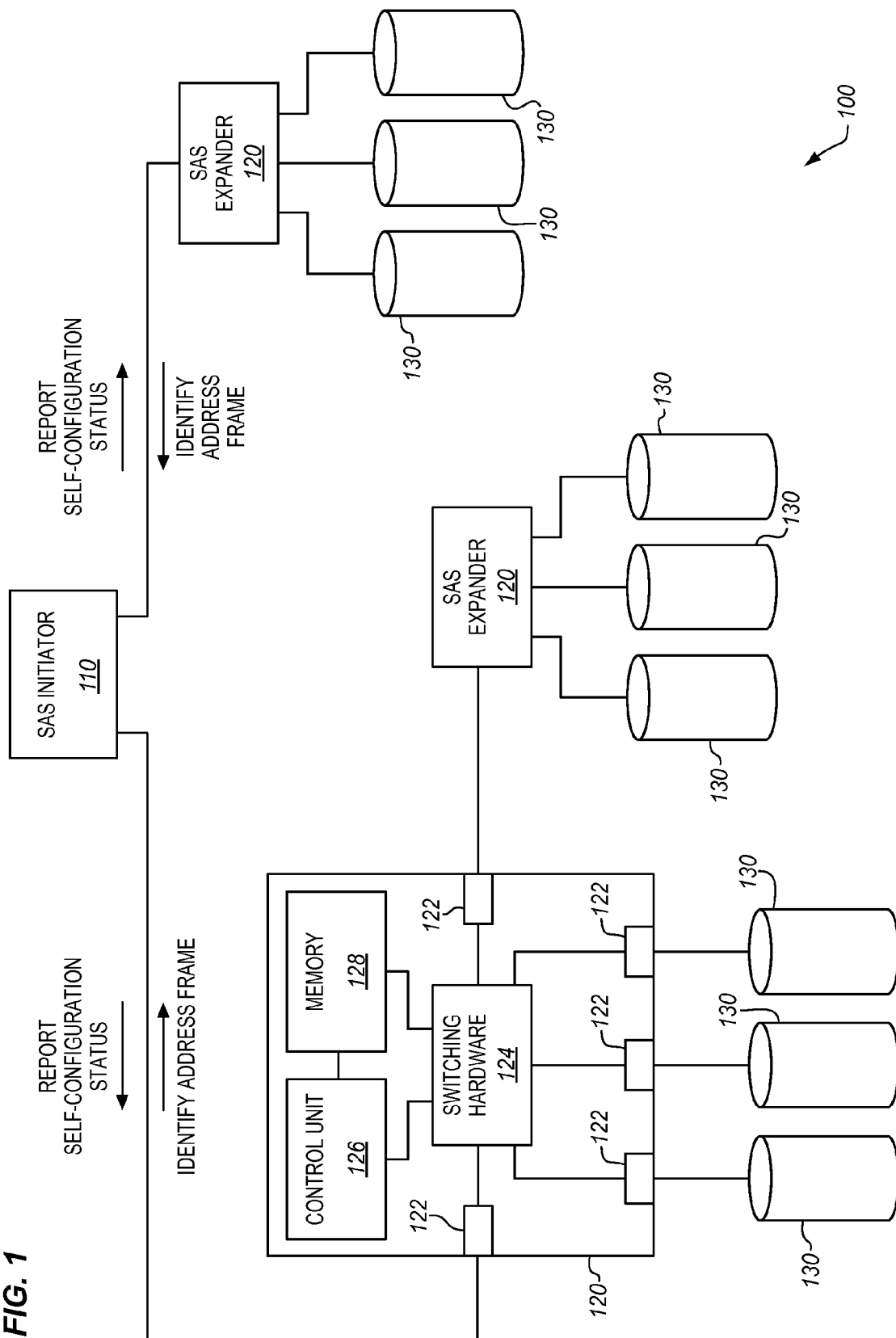
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**FIG. 1**



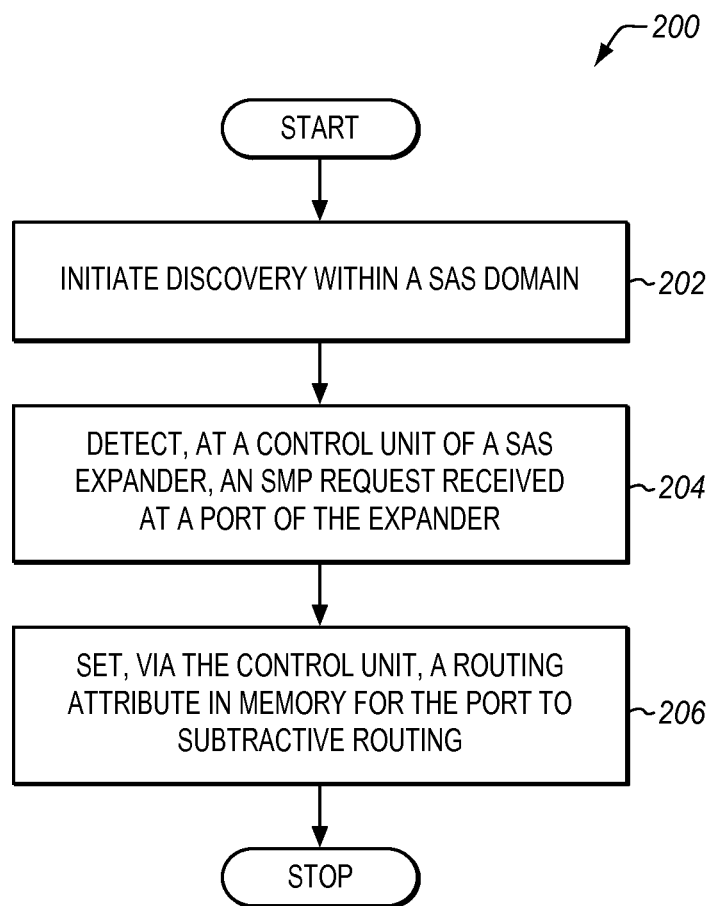
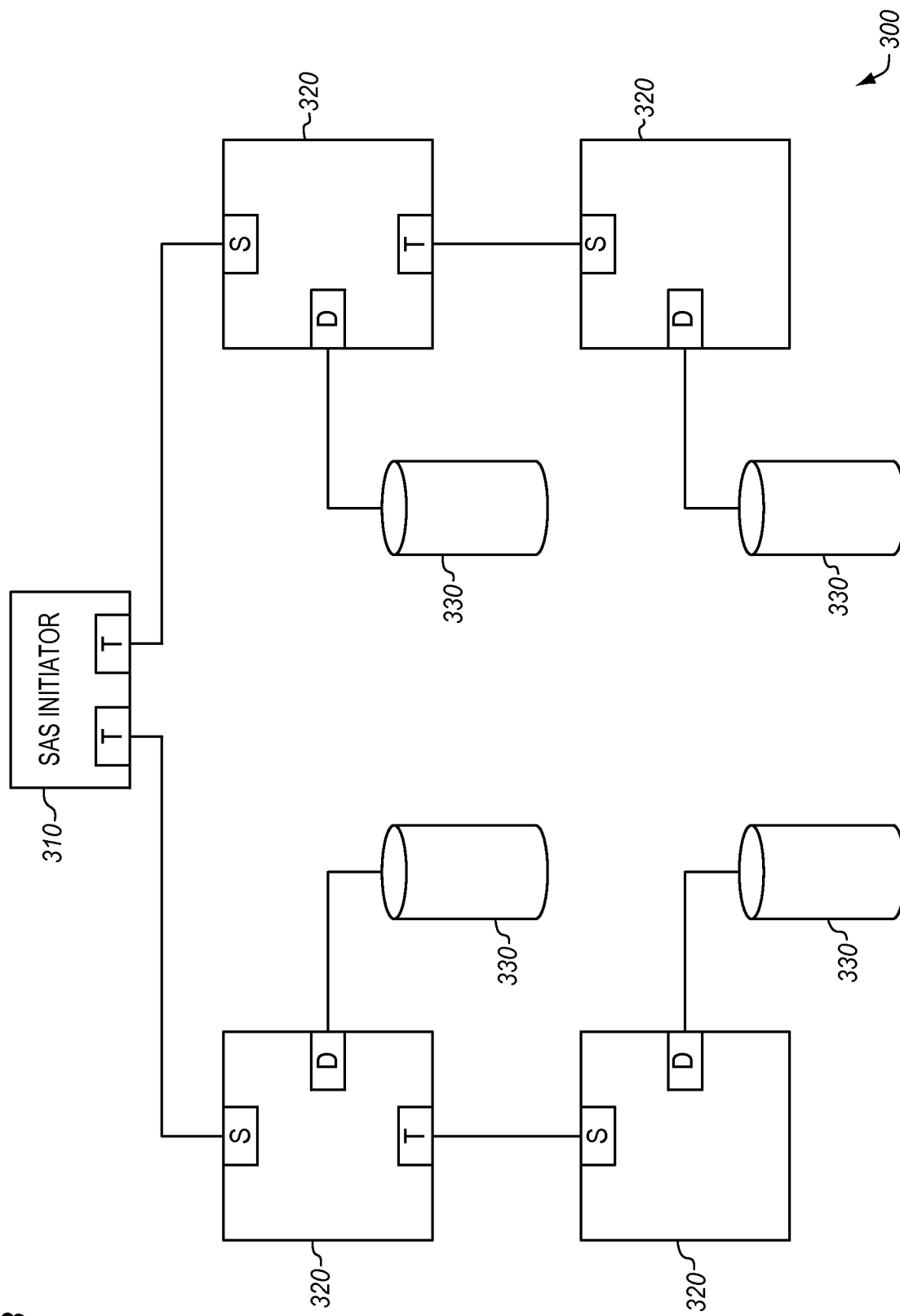
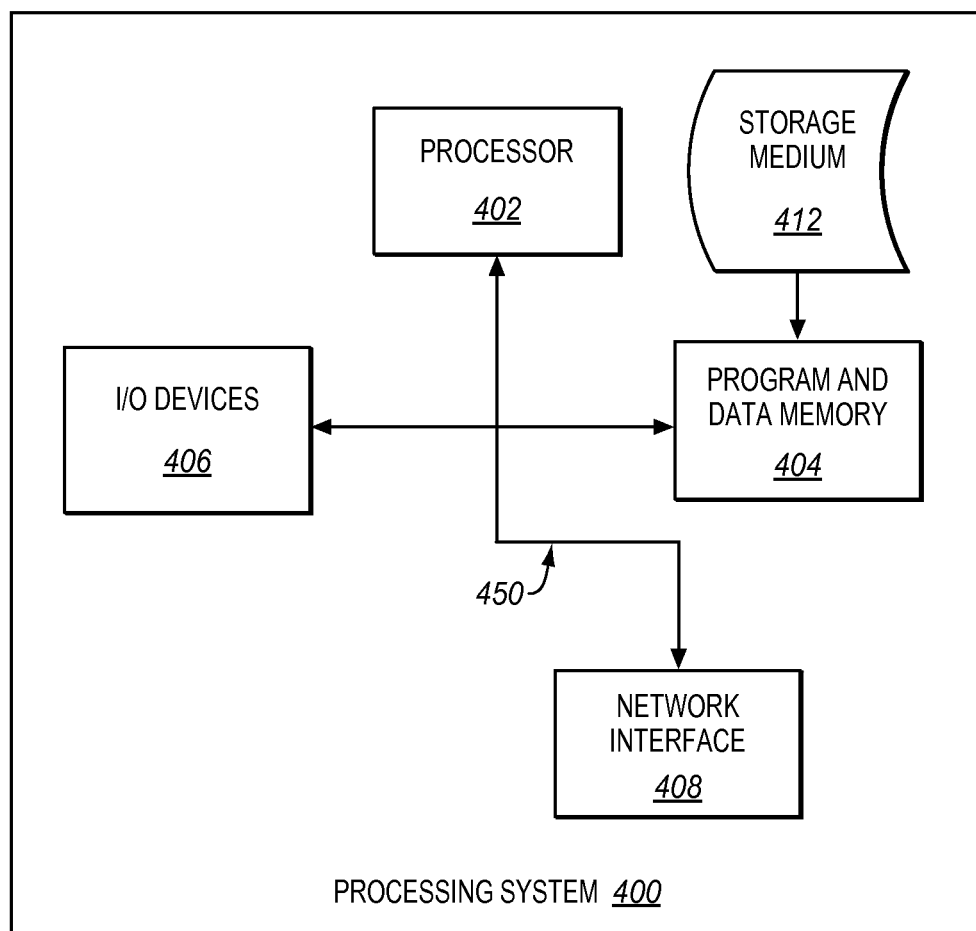
**FIG. 2**

FIG. 3



**FIG. 4**

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# METHODS AND STRUCTURE FOR SERIAL ATTACHED SCSI EXPANDERS THAT SELF-CONFIGURE BY SETTING ROUTING ATTRIBUTES OF THEIR PORTS BASED ON SMP REQUESTS

## BACKGROUND

### 1. Field of the Invention

The invention relates generally to Serial Attached SCSI (SAS) systems, and more specifically relates to SAS expanders.

### 2. Discussion of Related Art

In SAS domains (i.e., electronic systems implementing a switched SAS fabric) it is common for a SAS initiator to communicate with a large number of SAS or Serial Advanced Technology Attachment (SATA) end devices. The end devices may comprise, for example, SAS/SATA storage devices that provision one or more logical volumes of data. In a SAS domain, the end devices may be coupled for communication with the initiator via one or more SAS expanders. The SAS expanders serve to establish switched temporary communication channels between the initiator and the various storage devices.

Each SAS expander includes multiple physical links with associated transceivers (PHYs). The PHYs are used to define SAS ports. For example, a SAS port made from a single PHY is referred to as a narrow port, while SAS ports that comprise multiple PHYs are referred to as wide ports.

When a SAS expander is first initialized (e.g., during discovery), each port of the expander has its routing attributes (i.e., the routing attributes of each of its PHYs) configured by an outside source. A routing attribute defines how the SAS expander decides to route incoming requests to establish communications between SAS devices. An example of such a request is an OPEN Address Frame (OAF). The routing attributes may be defined as “subtractive,” “table,” or “direct.”

Direct routing is used when a PHY is directly coupled with an end device (e.g., a storage device). The SAS expander is made aware of the end device during discovery. Thus, when an incoming request indicates the SAS address of the end device, the SAS expander may immediately establish connections with the end device using the port that is directly coupled with the device.

Table routing is used by a SAS expander when a port is coupled with a known set of SAS addresses (e.g., coupled with multiple devices via one or more expanders). A routing table is kept in memory and associated with the ports that have been set to table routing. The routing table indicates the SAS addresses that are available via the various table routing ports. When an incoming request is received that requests one of those SAS addresses, the appropriate port is used to forward the request.

Subtractive routing is used to define a “port of last resort.” A port with a subtractive routing attribute is used whenever a requested SAS address is not identified in a routing table at the expander and is not directly connected to the SAS expander. Ideally, there will be only one subtractive routing port per expander.

As normally implemented, routing attributes are configured manually by a systems engineer, typically using a configuration tool on a management system coupled with the expander. This is a time-consuming process, and can create problems if the SAS domain is not properly configured (i.e., due to human error). For example, if two ports that are coupled to each other each use subtractive routing, then incoming requests could potentially bounce between those

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two ports in an infinite loop. This may cause system instabilities, and may prevent complete discovery of the SAS domain.

In further systems, a SAS initiator may coordinate and manage the configuration of routing attributes of SAS expanders by discovering each SAS expander and programming the routing attributes each individual port of each expander. However, this is also a time-consuming process for the initiator that occupies a great deal of processing power and bandwidth at the SAS domain, because the initiator must communicate with each end device and expander of the domain.

Thus it is an ongoing challenge to configure the routing attributes of ports of SAS expanders in an efficient manner.

## SUMMARY

The present invention addresses the above and other problems, thereby advancing the state of the useful arts, by providing methods and structure for SAS expanders to automatically configure the routing attributes of their own ports. This helps to distribute the processing load across many devices in the SAS domain, which in turn increases the speed at which the routing attributes of the various expanders of the domain can be programmed.

In one aspect hereof, a method is provided for operating a Serial Attached SCSI (SAS) expander comprising multiple physical links with associated transceivers (PHYs), wherein the PHYs are configured into ports. The method comprises detecting, via a control unit of the expander, a discovery Serial Management Protocol (SMP) request received at a port of the expander. The method further comprises setting, via the control unit, a routing attribute in memory for the port to subtractive routing responsive to detecting the SMP request.

Another aspect hereof provides a Serial Attached SCSI (SAS) expander comprising multiple physical links with associated transceivers (PHYs), wherein the PHYs are configured into ports at the expander, and a memory that defines routing attributes for each of the ports. The SAS expander also comprises a control unit that is operable to detect a discovery Serial Management Protocol (SMP) request received at a port of the expander, and that is further operable to set the routing attribute for the port to subtractive routing responsive to detecting the SMP request.

Another aspect hereof provides a non-transitory computer readable medium embodying programmed instructions which, when executed by a processor, are operable for performing a method for operating a Serial Attached SCSI (SAS) expander comprising multiple physical links with associated transceivers (PHYs), wherein the PHYs are configured into ports. The method comprises detecting, via a control unit of the expander, a discovery Serial Management Protocol (SMP) request received at a port of the expander. The method further comprises setting, via the control unit, a routing attribute in memory for the port to subtractive routing responsive to detecting the SMP request.

Other exemplary embodiments (e.g., methods and computer-readable media relating to the foregoing embodiments) may be described below.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an exemplary SAS domain in accordance with features and aspects hereof.

FIG. 2 is a flowchart describing an exemplary method of operating a SAS expander in accordance with features and aspects hereof.

FIG. 3 is a block diagram illustrating an exemplary SAS domain with ports that have been configured in accordance with features and aspects hereof.

FIG. 4 illustrates a processing system operable to execute a computer readable medium embodying programmed instructions to perform desired functions in an exemplary embodiment.

#### DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an exemplary Serial Attached SCSI (SAS) domain **100** in accordance with features and aspects hereof. SAS domain **100** couples a SAS initiator **110** with a number of end devices **130** (e.g., SAS or Serial Advanced Technology Attachment (SATA) targets). SAS initiator **110** is coupled to these target devices via enhanced SAS expanders **120**. Thus, in an operating environment, as commands are generated by SAS initiator **110** and directed to end devices **130**, SAS expanders **120** may establish connections between SAS initiator **110** and end devices **130**.

SAS initiator **110** comprises any suitable SAS initiator device operable to generate commands directed to end devices **130**. For example, SAS initiator **110** may read or write data on end devices **130** based upon input from a host. Initiator **110** may comprise an independent SAS device, a Host Bus Adapter (HBA) of a host, an integrated component of a host, etc. During discovery (i.e., prior to normal operation of the system), SAS initiator **110** generates discovery commands that are disseminated throughout SAS domain **100** in order to identify the devices on SAS domain **100**.

End devices **130** may comprise any suitable SAS or SATA target devices in accordance with SAS/SATA specifications. For example, end devices **130** may comprise storage devices that provision logical volumes of data which are accessible to SAS initiator **110**.

Enhanced SAS expanders **120** are capable of routing commands between initiator **110** and end devices **130**. For example, expander **120** may establish connections between initiator **110** and one or more of end devices **130**. In this embodiment, each expander **120** includes multiple SAS ports **122** which are switchably connected via switching hardware **124**. A control unit **126** within each expander manages the general operations of the expander.

Each SAS port **122** comprises one or more physical links with associated transceivers (PHYs). Switching hardware **124** is operable to establish connections between various PHYs in order to enable communications between them. The operations of switching hardware **124** (e.g. a “crossbar” switch) are managed by control logic and hardware at expander **120**, which in this embodiment is a component of control unit **126**. Control unit **126** may be implemented, for example, as custom circuitry, as a special or general purpose processor executing programmed instructions stored in an associated program memory, or some combination thereof.

Each enhanced SAS expander **120** has been improved to self-configure the routing attributes of its ports during or after the discovery process on SAS domain **100**. Specifically, enhanced SAS expanders **120** may determine whether each port should be set to table routing, to direct routing, or to subtractive routing. This is accomplished by logic implemented at control unit **126** described below.

During the discovery process, each control unit **126** waits for receipt of a Serial Management Protocol (SMP) REPORT SELF-CONFIGURATION STATUS command at a port **122** of its expander **120** (e.g., before initiating any discovery processes). These requests are generated by SAS initiator **110** during discovery, and are propagated throughout the SAS

domain to the SAS expanders. When a REPORT SELF-CONFIGURATION STATUS command is received at the expander, control unit **126** identifies the port **122** that received the command. The port that received the command is coupled (e.g., via one or more expanders) to the SAS initiator, and therefore the routing attributes for the port are set to subtractive routing. If the port that received the command is directly coupled with the SAS initiator, the port may alternatively be set to direct routing instead of subtractive routing.

Control unit **126** then identifies each port that did not receive the REPORT SELF-CONFIGURATION STATUS command described above, and initiates a SAS handshake with each device directly coupled to such ports. A SAS handshake may involve transmitting an SMP IDENTIFY Address Frame (IAF) to each device that is directly coupled to a port of the expander. The handshake process may further include receiving an IDENTIFY address frame from each directly coupled device, indicating whether the directly coupled device is another SAS expander or is an end device. If the device is an end device, then control unit **126** sets the routing attribute for the port to direct routing. Alternatively, if the device is another expander, control unit **126** sets the routing attribute to table routing, and forwards/propagates a REPORT SELF-CONFIGURATION STATUS command to the coupled expander, which then performs its own processes to configure the routing attributes of its PHYs in response to receiving the command.

After the routing attributes for the ports have been configured, a memory **128** (e.g., a set of registers, a solid-state memory, RAM, etc.) at SAS expander **120** may be populated with the routing information to allow use of the ports that are configured for table routing. This may occur in accordance with SAS standards well known to those of ordinary skill in the art. For example, the SAS expander may comprise a self-configuring expander device as defined in accordance with SAS standards (e.g., SAS version 2, revision 15, issued by the T10 committee on 19 November 2008 and herein incorporated by reference). In this context, “self-configuring” indicates that the SAS expander may populate its own routing tables with SAS addresses. As defined in SAS standards, “self-configuring” does not refer to expanders that may configure the routing attributes of their own ports.

The enhanced SAS expanders **120** described above ensure that SAS expanders **120** that are “beneath” SAS initiator **110** will subtractively route requests “up” towards SAS initiator **110**. As used herein, expanders further from the root complex (i.e., expanders further from the SAS initiator) are referred to as downstream expanders. The application of routing attributes described herein prevents situations where improperly configured routing attributes of SAS expanders would otherwise result in a nonfunctional or unstable SAS domain. Furthermore, programming routing attributes at the SAS expanders (instead of remotely via SAS initiator **110**) saves processing resources at SAS initiator **110**, which may increase the speed of the discovery process.

Note that the particular arrangement of components described herein is merely intended to be exemplary, and one of ordinary skill in the art will appreciate that the specific arrangement and configuration of SAS domain devices is merely a matter of design choice.

FIG. 2 is a flowchart describing an exemplary method **200** of operating a SAS expander in accordance with features and aspects hereof. The method of FIG. 2 may be operable in a SAS domain such as described above with regard to FIG. 1.



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The steps of the flowcharts described herein are not all inclusive and may include other steps not shown. The steps described herein may also be performed in an alternative order.

In step **202**, SAS discovery processes are initiated within a SAS domain. SAS discovery processes are typically performed at start-of-day, and may be used to initially configure the SAS domain (e.g., discovery may be used to program the routing attributes of the various ports of SAS expanders within the domain, routing tables used to establish connections between remote devices, etc.). For example, discovery may occur after a power on reset of the SAS domain. The initial configuration set up during/after discovery ensures that SAS communications can be established between the various elements of the domain. The discovery process may be started by a SAS initiator, and may be propagated to remote devices by a switched fabric of SAS expanders (e.g., a Service Delivery Subsystem (SDS) of the SAS domain).

For example, the SAS initiator may start a SAS handshake with one or more devices that it is directly coupled with. This may include sending an IDENTIFY address frame to the directly coupled device, and receiving an IDENTIFY address frame from the directly coupled device in response. The SAS initiator may then determine, based on the received IDENTIFY frame, that the device is a SAS expander. The SAS initiator may then transmit an SMP REPORT SELF-CONFIGURATION STATUS command/request to the expander.

In step **204**, a control unit of the SAS expander detects receipt of an SMP request at one of its ports. For example, the expander may receive the SMP request because the request is directly addressed to the SAS expander. This request comprises an SMP REPORT SELF-CONFIGURATION STATUS command.

In step **206**, the control unit of the expander sets the routing attributes for the port that received the SMP request to subtractive routing. Thus, in this system, the subtractive routing ports, when followed in sequence from expander to expander, all lead upstream towards the SAS initiator.

The expander may then initiate SAS handshakes with devices that are directly coupled with its remaining ports. During the SAS handshake for a given port, the expander transmits IDENTIFY address frames to directly coupled devices (i.e., the devices that are directly coupled to the unconfigured ports), and receives IDENTIFY address frames from the directly coupled devices. If an IDENTIFY address frame indicates that a directly coupled device is an end device (such as a SAS/SATA target), then the port is set to direct routing.

However, if the directly coupled port is another SAS expander, then the first SAS expander may send an SMP REPORT SELF-CONFIGURATION STATUS command. The receipt of the SMP REPORT SELF-CONFIGURATION STATUS command may trigger method **200** at the other expander. Thus, the SMP command/request enables downstream SAS expanders to properly configure their own routing attributes according to method **200**, and so on, in a recursive process.

Because of the nature of the processes described above, it may be desirable for the routing attribute configuration process described above to be performed in a single initiator environment.

FIG. 3 is a block diagram illustrating an exemplary SAS domain **300** with ports that have been configured in accordance with features and aspects hereof. According to FIG. 3, a SAS initiator **310** (in this case, a controller of multiple storage devices on the SAS domain) includes multiple SAS ports.

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Each port has been initially configured by the controller to table routing. Further according to FIG. 3, each SAS expander **320** has configured the routing attributes of its ports. Ports that are directly coupled with end devices **330** are set to direct routing, while ports that are directly coupled with an upstream SAS expander are set to subtractive routing. Ports that are directly coupled with downstream expanders are set to table routing.

Embodiments disclosed herein can take the form of software, hardware, firmware, or various combinations thereof. In one particular embodiment, software is used to direct a processing system of expander **120** to perform the various operations disclosed herein. FIG. 4 illustrates a processing system **400**, such as in enhanced expander **120** of FIG. 1, operable to execute a computer readable medium embodying programmed instructions to perform desired functions in an exemplary embodiment. Processing system **400** is operable to perform the above operations by executing programmed instructions tangibly embodied on computer readable storage medium **412**. In this regard, embodiments of the invention can take the form of a computer program accessible via computer-readable medium **412** providing program code for use by a computer or any other instruction execution system. For the purposes of this description, computer readable storage medium **412** can be anything that can contain or store the program for use by the computer.

Computer readable storage medium **412** can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor device. Examples of computer readable storage medium **412** include a solid state memory, a magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W), and DVD.

Processing system **400**, being suitable for storing and/or executing the program code, includes at least one processor **402** coupled to program and data memory **404** through a system bus **450**. Program and data memory **404** can include local memory employed during actual execution of the program code, bulk storage, and cache memories that provide temporary storage of at least some program code and/or data in order to reduce the number of times the code and/or data are retrieved from bulk storage during execution.

Input/output or I/O devices **406** (e.g., PHYs) can be coupled either directly or through intervening I/O controllers. Network adapter interfaces **408** may also be integrated with the system to enable processing system **400** to become coupled to other data processing systems or storage devices through intervening private or public networks. Modems, cable modems, IBM Channel attachments, SCSI, Fibre Channel, and Ethernet cards are just a few of the currently available types of network or host interface adapters.

While the invention has been illustrated and described in the drawings and foregoing description, such illustration and description is to be considered as exemplary and not restrictive in character. One embodiment of the invention and minor variants thereof have been shown and described. In particular, features shown and described as exemplary software or firmware embodiments may be equivalently implemented as customized logic circuits and vice versa. Protection is desired for all changes and modifications that come within the spirit of the invention. Those skilled in the art will appreciate variations of the above-described embodiments that fall within the scope of the invention. As a result, the invention is not limited to the specific examples and illustrations discussed above, but only by the following claims and their equivalents.

What is claimed is:

1. A Serial Attached SCSI (SAS) expander comprising:  
multiple physical links with associated transceivers  
(PHYs), wherein the PHYs are configured into ports at  
the expander;
- a memory that defines routing attributes for each of the  
ports; and
- a control unit operable to detect a discovery Serial Man-  
agement Protocol (SMP) request received at a port of the  
expander, and further operable to set the routing attribute  
for the port to subtractive routing responsive to detecting  
the SMP request if the SMP request comprises a  
REPORT SELF-CONFIGURATION STATUS com-  
mand.
2. The SAS expander of claim 1 wherein:  
the control unit is further operable to determine, if the SMP  
request comprises a REPORT SELF-CONFIGURA-  
TION STATUS command, that the port that received the  
SMP request is coupled for communication with a SAS  
initiator.
3. The SAS expander of claim 1 wherein:  
the control unit is further operable to transmit REPORT  
SELF-CONFIGURATION STATUS messages to  
directly coupled expanders.
4. The SAS expander of claim 1 wherein:  
the control unit is further operable to propagate an SMP  
IDENTIFY address frame request via an other port of  
the SAS expander, and is further operable to determine,  
based upon an IDENTIFY address frame received in  
response to the propagated SMP IDENTIFY address  
frame, whether to configure the routing attribute for the  
other port to table routing or direct routing.
5. The SAS expander of claim 1 wherein:  
the control unit is further operable, at power on of the SAS  
expander and before receiving the SMP request, to con-  
figure all ports of the SAS expander to table routing.
6. The SAS expander of claim 4 wherein:  
the control unit is further operable to determine, based  
upon the received IDENTIFY address frame, whether a  
SAS device coupled with the other port is a SAS  
expander or an end device, is operable to configure the  
routing attribute for the other port to table routing if the  
SAS device is an expander, and is operable to configure  
the routing attribute for the other port to direct routing if  
the SAS device is an end device.
7. The SAS expander of claim 4 wherein:  
the control unit is further operable to populate a routing  
table based upon information received in one or more  
IDENTIFY address frames, and to establish connections  
with ports set to table routing by consulting the routing  
table.
8. A method for operating a Serial Attached SCSI (SAS)  
expander comprising multiple physical links with associated  
transceivers (PHYs), wherein the PHYs are configured into  
ports, the method comprising:  
detecting, via a control unit of the expander, a discovery  
Serial Management Protocol (SMP) request received at  
a port of the expander; and  
setting, via the control unit, a routing attribute in memory  
for the port to subtractive routing responsive to detecting  
the SMP request if the SMP request comprises a  
REPORT SELF-CONFIGURATION STATUS com-  
mand.
9. The method of claim 8 further comprising:  
determining, if the SMP request comprises a REPORT  
SELF-CONFIGURATION STATUS command, that the

- port that received the SMP request is coupled for com-  
munication with a SAS initiator.
10. The method of claim 8 further comprising:  
transmitting REPORT SELF-CONFIGURATION STA-  
TUS messages to expanders that are directly coupled  
with the expander.
  11. The method of claim 8 further comprising:  
propagating, at the expander, an SMP IDENTIFY address  
frame via an other port of the SAS expander; and  
determining at the control unit, based upon an IDENTIFY  
address frame received in response to the propagated  
IDENTIFY address frame, whether to configure the  
routing attribute for the other port to table routing or  
direct routing.
  12. The method of claim 8 wherein:  
the control unit is further operable, at power on of the SAS  
expander and before receiving the SMP request, to con-  
figure all ports of the SAS expander to table routing.
  13. The method of claim 11 further comprising:  
determining at the control unit, based upon the received  
IDENTIFY address frame, whether a SAS device  
coupled with the other port is a SAS expander or an end  
device;  
configuring, via the control unit, the routing attribute for  
the other port to table routing if the SAS device is an  
expander; and  
configuring, via the control unit, the routing attribute for  
the other port to direct routing if the SAS device is an end  
device.
  14. The method of claim 11 further comprising:  
populating, via the control unit, a routing table based upon  
information received in one or more IDENTIFY address  
frames; and  
establishing connections with ports set to table routing by  
consulting the routing table.
  15. A non-transitory computer readable medium embody-  
ing programmed instructions which, when executed by a  
processor, are operable for performing a method for operating  
a Serial Attached SCSI (SAS) expander comprising multiple  
physical links with associated transceivers (PHYs), wherein  
the PHYs are configured into ports, the method comprising:  
detecting, via a control unit of the expander, a discovery  
Serial Management Protocol (SMP) request received at  
a port of the expander; and  
setting, via the control unit, a routing attribute in memory  
for the port to subtractive routing responsive to detecting  
the SMP request if the SMP request comprises a  
REPORT SELF-CONFIGURATION STATUS com-  
mand.
  16. The medium of claim 15 further comprising:  
determining, if the SMP request comprises a REPORT  
SELF-CONFIGURATION STATUS command, that the  
port that received the SMP request is coupled for com-  
munication with a SAS initiator.
  17. The medium of claim 15 wherein the method further  
comprises:  
transmitting REPORT SELF-CONFIGURATION STA-  
TUS messages to expanders that are directly coupled  
with the expander.
  18. The medium of claim 15 wherein the method further  
comprises:  
propagating, at the expander, an SMP IDENTIFY address  
frame via an other port of the SAS expander; and  
determining at the control unit, based upon an IDENTIFY  
address frame received in response to the propagated

IDENTIFY address frame, whether to configure the routing attribute for the other port to table routing or direct routing.

**19.** The medium of claim **18** wherein the method further comprises:

determining at the control unit, based upon the received IDENTIFY address frame, whether a SAS device coupled with the other port is a SAS expander or an end device;

configuring, via the control unit, the routing attribute for the other port to table routing if the SAS device is an expander; and

configuring, via the control unit, the routing attribute for the other port to direct routing if the SAS device is an end device.

**20.** The medium of claim **18** wherein the method further comprises:

populating, via the control unit, a routing table based upon information received in one or more IDENTIFY address frames; and

establishing connections with ports set to table routing by consulting the routing table.

\* \* \* \* \*